# Mechanical Design and Configuration of Penetrations for the Europa Clipper Avionics Vault Structure

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# Agenda

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- Radiation Shielding
- Electromagnetic Interference (EMI) Shielding
- Vault Penetrations
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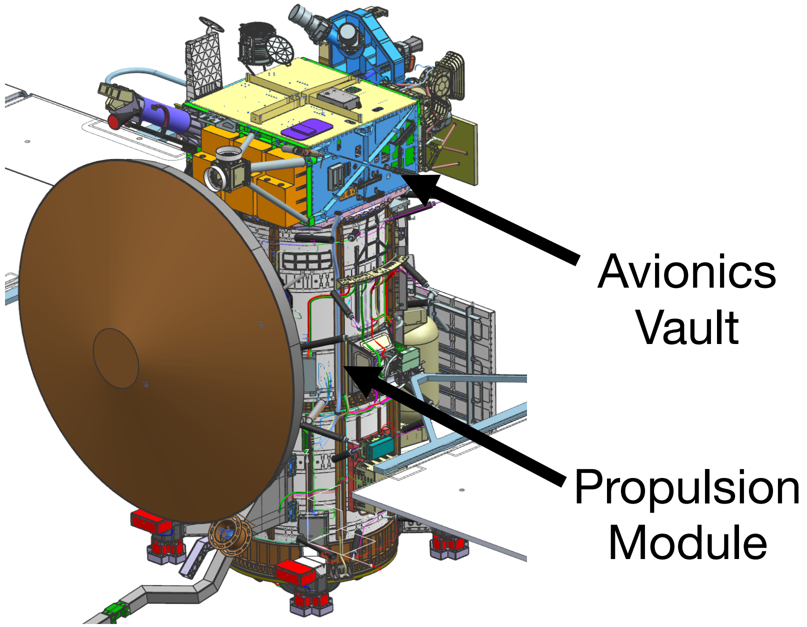
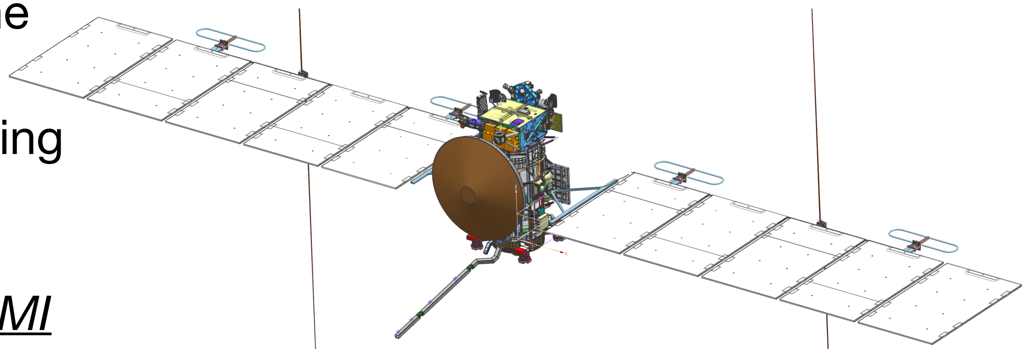
- Mock-up Vault Panel EMI Test
- Summary

# Introduction

# Introduction

- The objectives of the Europa Clipper Spacecraft are to study Europa's ice shell, oceans, composition, and geology using nine instruments.
- To meet these objectives, the spacecraft has instrument electronic boxes, radiation monitors, power supplies, computers, IMUs, star trackers, thermal pumps, wheel drive electronics, and digital sun sensor electronic boxes *that require protection from Jupiter's radiation environments.*
- All of these electronic boxes mentioned above are shielded from Jupiter's radiation inside of a box structure known as the Avionics Vault.
- There are about 26 electronic boxes inside the vault.
- More than 150 cables need to penetrate the vault panels.
- Fluid lines, that gather heat from these electronic boxes, penetrate the vault panels in order to distribute heat to the rest of the spacecraft.
- Four vent holes are in each corner of the vault in order to vent air during launch and cruise.
- *The challenge in the design of the vault is accommodating these significant numbers of penetrations while maintaining radiation and EMI shielding effectiveness.*



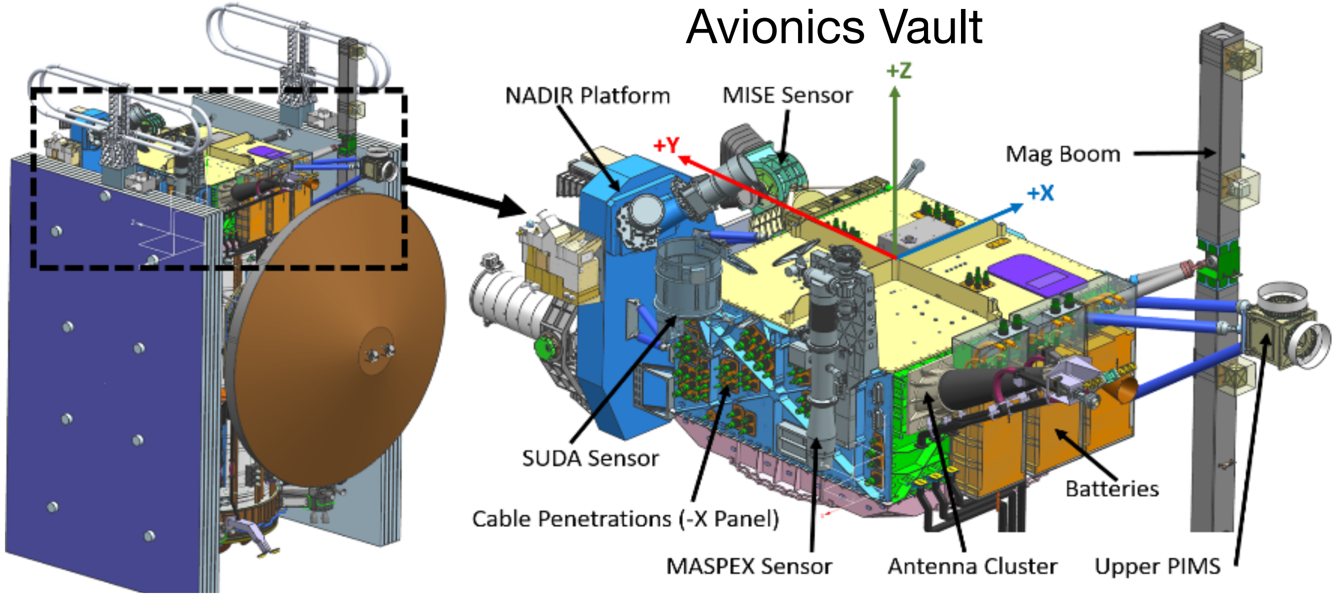



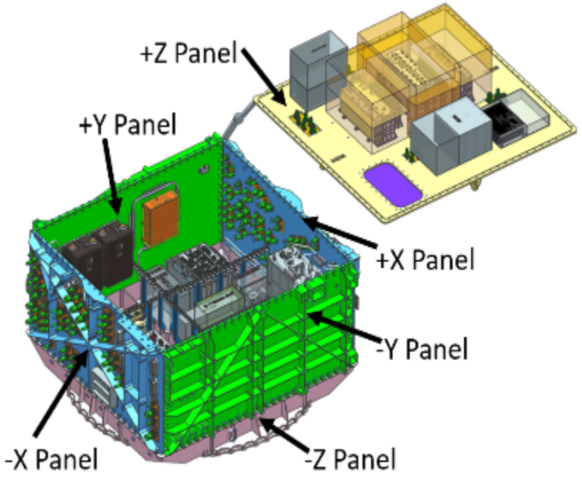
Deployed Europa Clipper Spacecraft

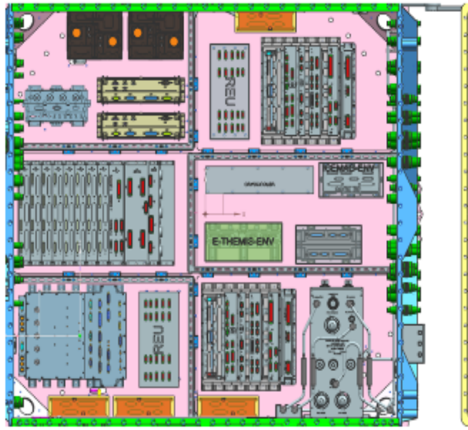
# Avionics Vault Configuration

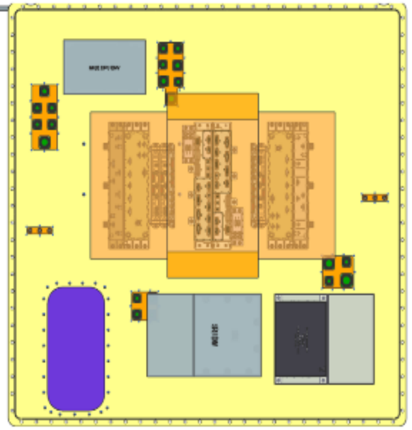
# Avionics Vault Configuration

- The vault is roughly a 1.4m x 1.4m x 1m box structure composed of six panels
- The vault is a multifunctional structure.
- In addition to radiation and EMI shielding, the vault is required to provide significant structural support to numerous components both inside and outside the vault.
- Furthermore, the vault structure requires good thermal conductivity in order for fluid lines to gather heat from electronic boxes mounted on the panels.
- Due to these desired requirements, the vault panels were chosen to be made out of aluminum 7075.





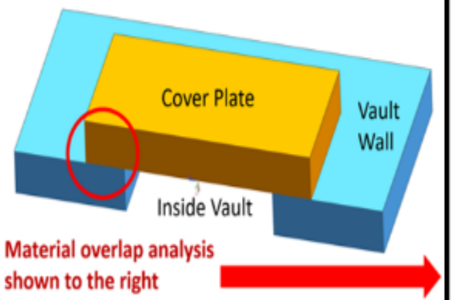
# Radiation Shielding

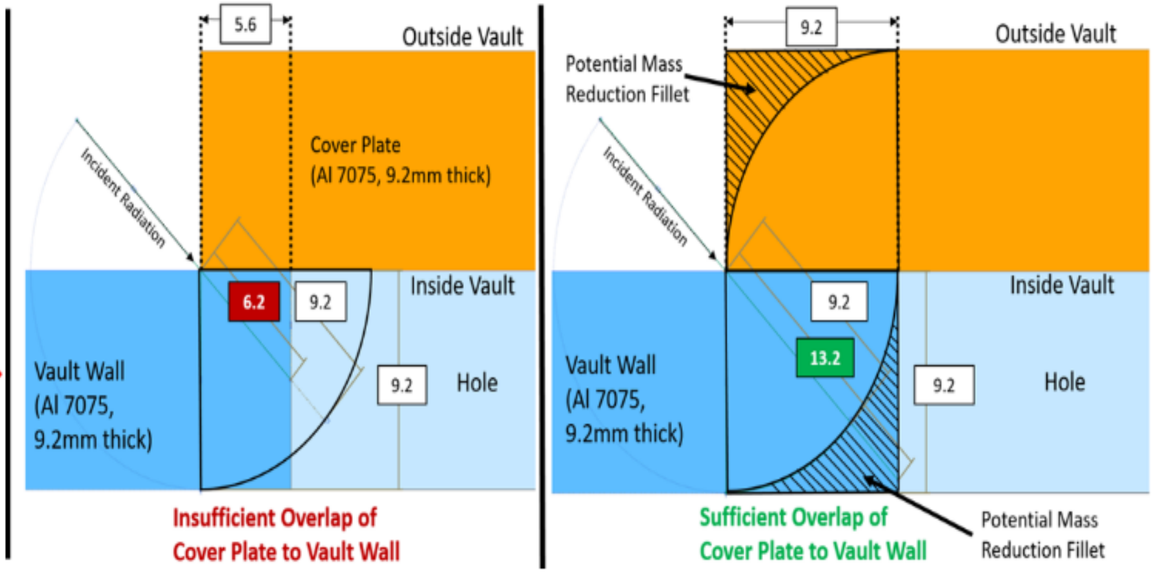
# Radiation Shielding

- The main purpose of the vault is to shield all sensitive electronics on the Europa Clipper spacecraft from the radiation environments around Jupiter.
- Inside the vault, the ionizing radiation dose rate is required to be 150 krad(Si)/s.
- In order to meet this requirement, the vault needs to provide a radiation shielding effectiveness that is equivalent to 9.2 mm thick Al 7075.
- This means that the wall thickness of the Al 7075 vault panels need to be 9.2 mm thick, and Al 7075 mechanical joints that close the vault need to overlap by 9.2mm

- The vault also has stainless steel alloys and tantalum alloys as radiation shields.
- A conservative approach to estimate the required radiation shielding thickness for these different metals ($t_{new}$) is to multiply the Al 7075 radiation shielding thickness by the ratio of the material densities

$$t_{new} = 9.2\left(\frac{\rho_{Al\ 7075}}{\rho_{new}}\right)$$

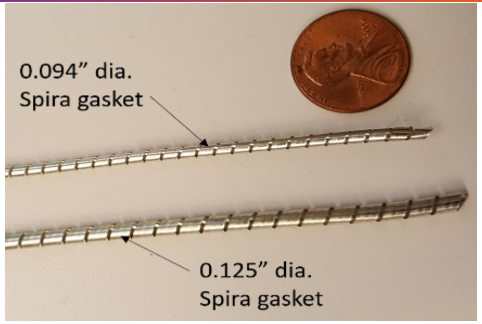


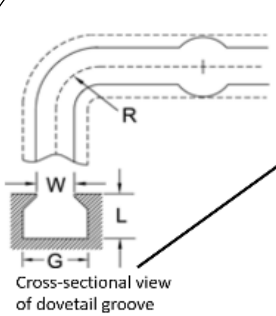



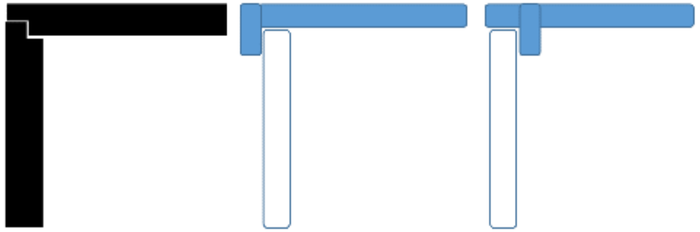
# EMI Shielding

# EMI Shielding

- The Avionics Vault is required to achieve an EMI shielding effectiveness (SE) of at least 70 dB at the REASON radar frequencies of 9 MHz and 60 MHz when measured at 1 m from the vault panel
- Since the vault consists of multiple panels and hundreds of penetrations, the resulting seams can significantly degrade the vault's EMI SE
- Any metal-to-metal joint creates a seam, which can result in gaps for EMI signals to leak out. The vault design incorporates three techniques to minimize EMI signal leakage through seams:
  - *Spira-Shield EMI gaskets, Labyrinth L-configuration seams, and fastener spacing.*
- The Spira-Shield EMI gasket is a spiral wound metal made out of spring tempered beryllium copper, and is installed into the vault panels via dovetail grooves
- The Labyrinth L-configurations interfere with the direct line-of-sight access for electromagnetic radiation to leak out
- Recommended fastener spacing to minimize gaps at each of these seams is no more than 50.8 mm (2 inches)



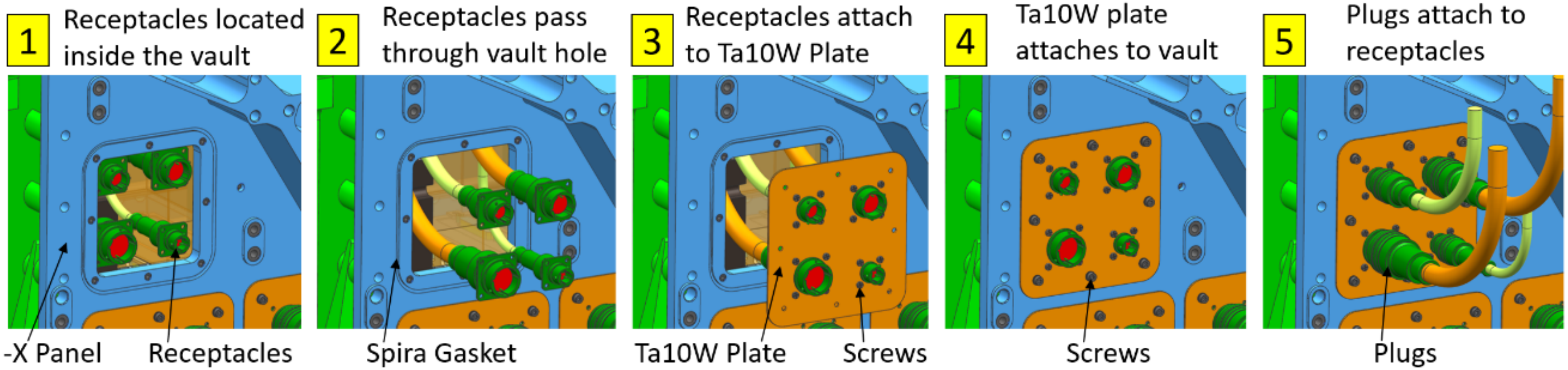
*Labyrinth L-configuration seams*

# Vault Penetrations

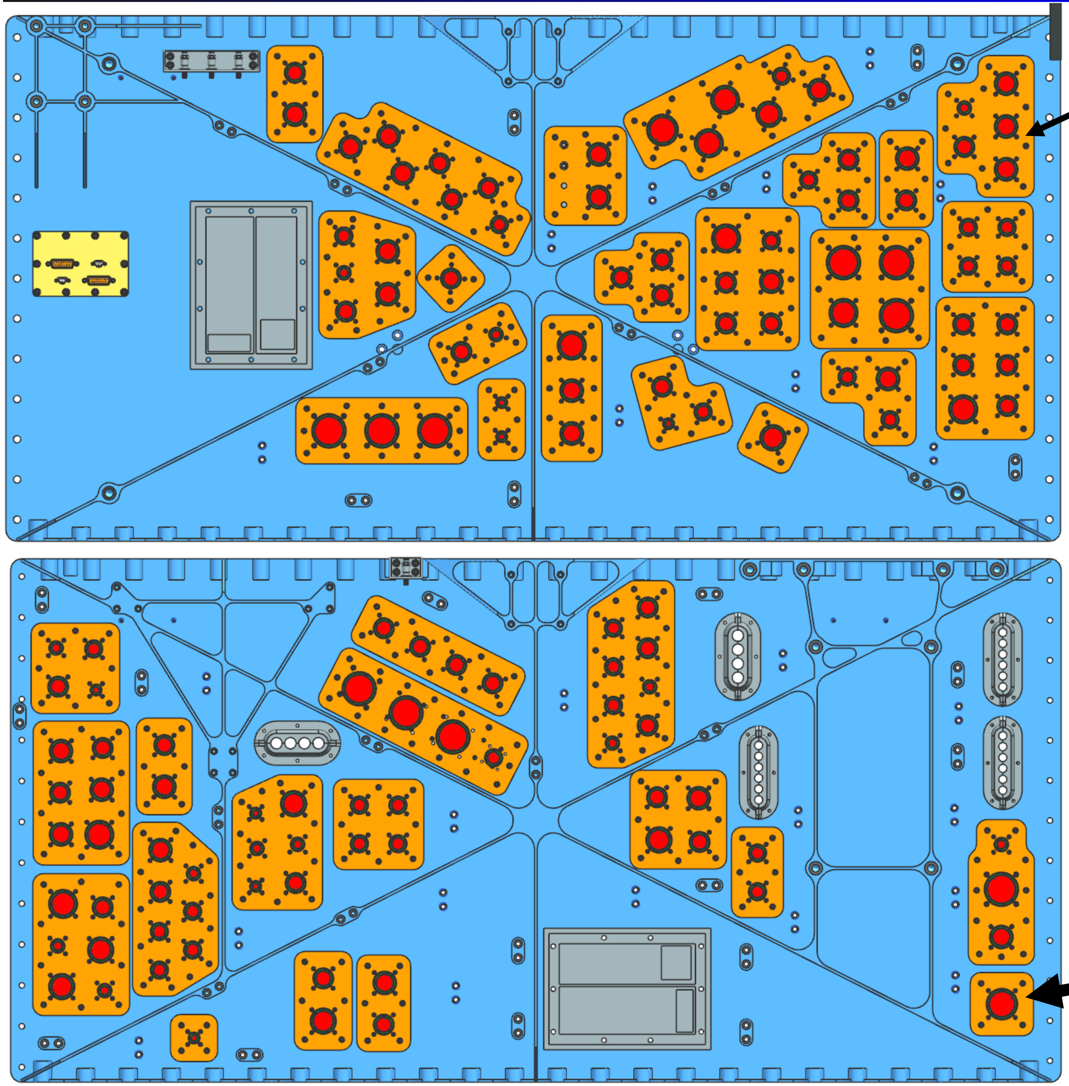
Receptacle Connectors
Pass-through Cables
Vent Holes
Fluid Lines

# Receptacle Connectors

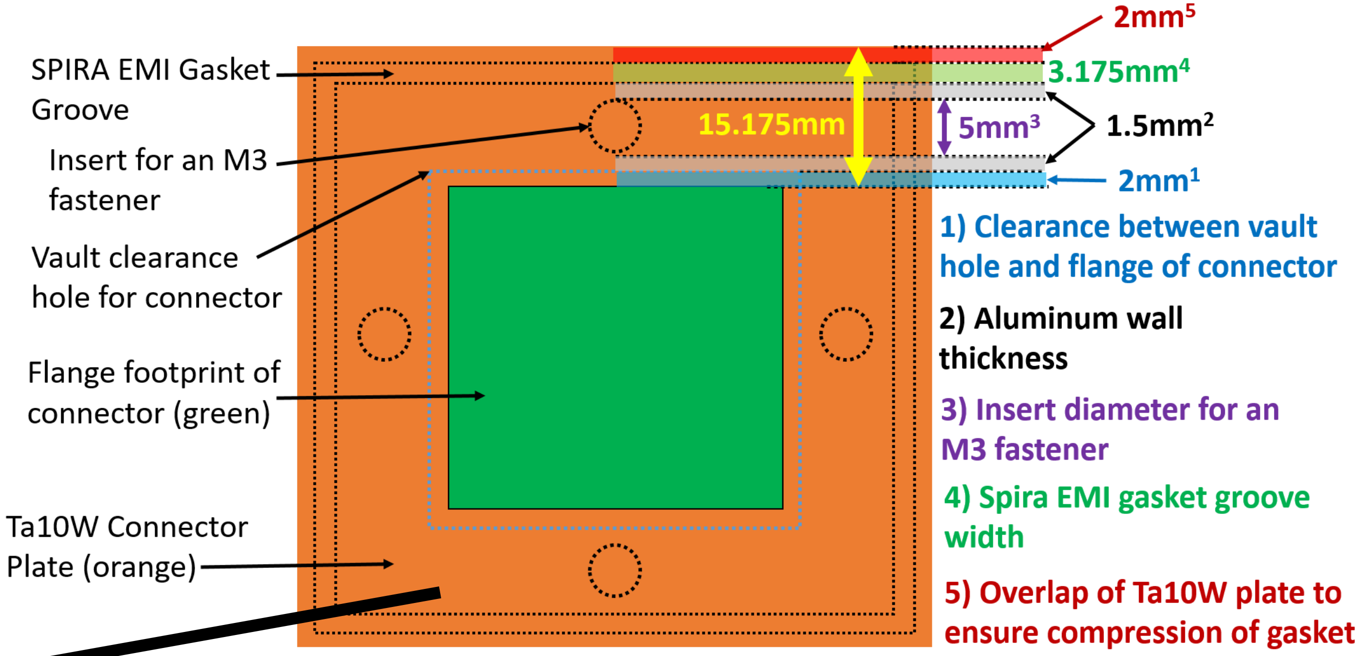
- The vast majority of cables are penetrating the vault using rear mounted, flanged, MIL-DTL-38999 series II circular receptacle connectors
- These connectors require a mounting plate no more than 1.42mm thick
- Advantageous to mount connectors outside the vault for access, and on separate plates for design adaptability and modularity
- Promising material of choice is Tantalum Tungsten Alloy (Ta10W)
  - High-Z material that is 20% more mass efficient at shielding radiation compared to aluminum
  - Requires ~1.3mm thickness for radiation shielding
  - Just as strong and as stiff as stainless steel 316
  - Much lower thermal conductivity than aluminum



# Ta10W Connector Plates

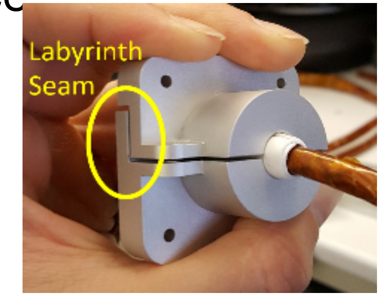


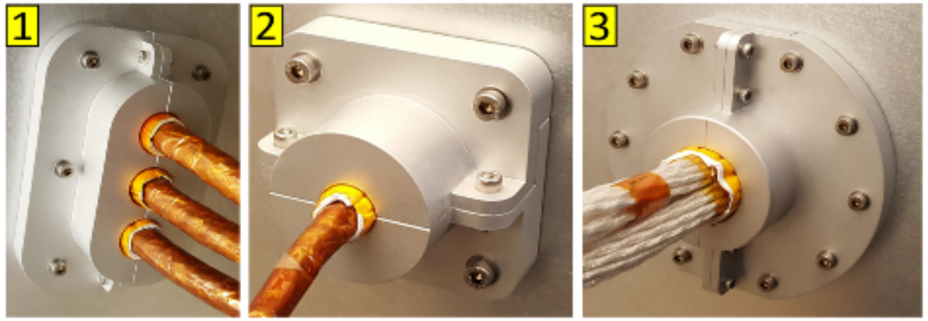
- ~38 unique Ta10W connector plates
- Minimizing cable lengths and optimizing spacecraft integration access to the connectors/cables drove the location and quantity of these connector plates



# Pass-through Cables

- Adding connectors to a cable can cause impedance miss-match that impairs the quality of science data collected by an instrument.
- Some instruments have high voltage cables that are incompatible with connectors.
- In these instances, cables need to pass-through the vault panels with no connector.
- Clamshells made out of Al 6061 provide a method that allows cables to pass-through the vault panels and close the penetration hole for EMI and radiation shielding.



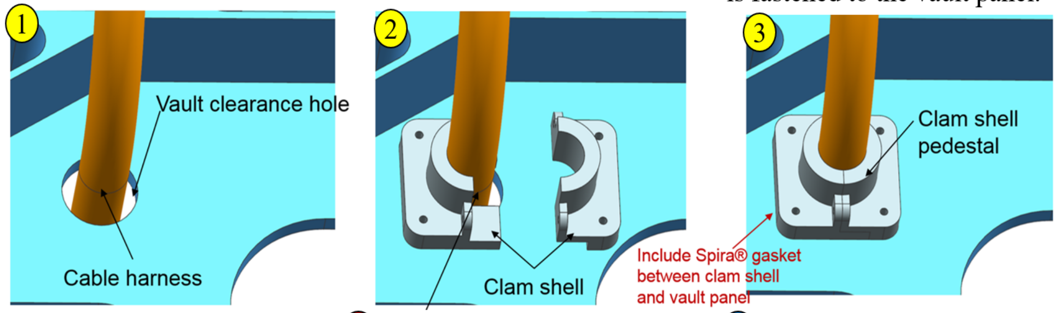



(1) A slotted clamshell, (2) single cable clamshell, and (3) cable bundle clamshell.

The cable (with connector) is fed through a clearance hole in the vault panel

A clamshell is placed onto the vault panel around the cable harness.

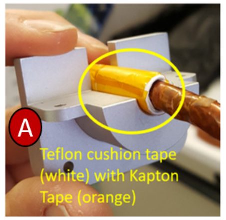
The clamshell is fastened together around the cable and is fastened to the vault panel.



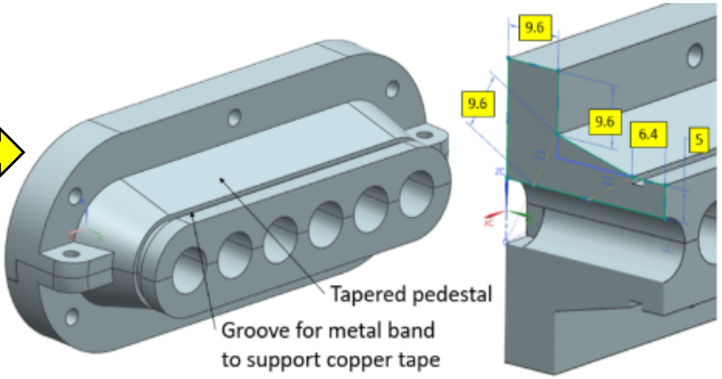

The vault clearance hole is sized to accommodate the diameter of the cable and the connector plug.

A Teflon cushion tape and black Kapton tape are wrapped around the portion of the cable that is clamped.

B Copper tape is externally wrapped around the cable, and terminate around the pedestal of the clamshell.


More detailed design of slotted clamshell



# Vent Holes

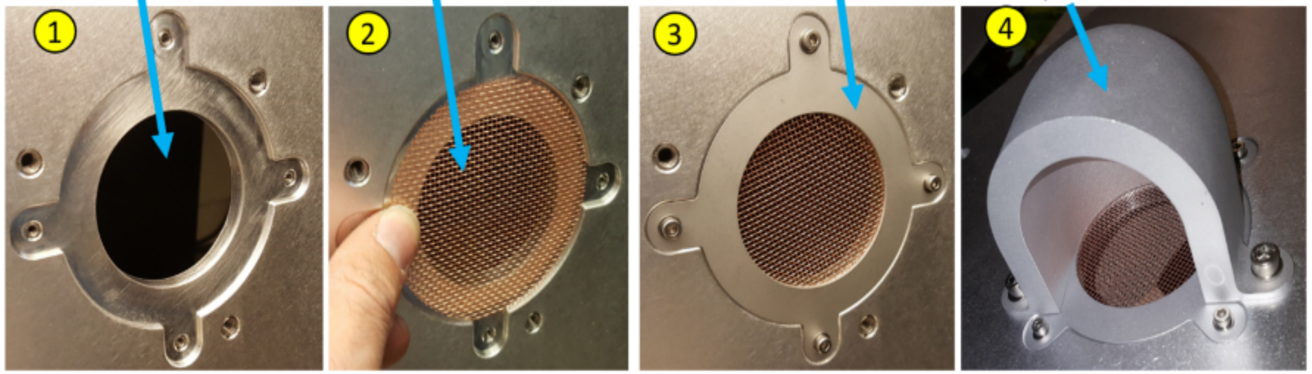
- During launch, the air inside the Avionics Vault needs to vent out in order to prevent the vault from becoming a pressurized vessel.
- Designed four 55mm diameter vent holes at each corner of the vault (see back up slides for details on sizing)
- There are three components used to close a vent hole for EMI and radiation shielding
  - A copper mesh that has hole openings less than 380 μm$^2$ (0.015 in$^2$) to seal for EMI signals
  - A stainless steel plate fastens on to compress the copper mesh plate into a counterbore hole
  - A radiation cover attaches over the stainless steel plate, which also directs the flow of venting air
- To minimize the mass of the radiation covers, the four vent holes exist at the corners of the vault where the radiation covers can take advantage of the radiation shielding provided by the propulsion module

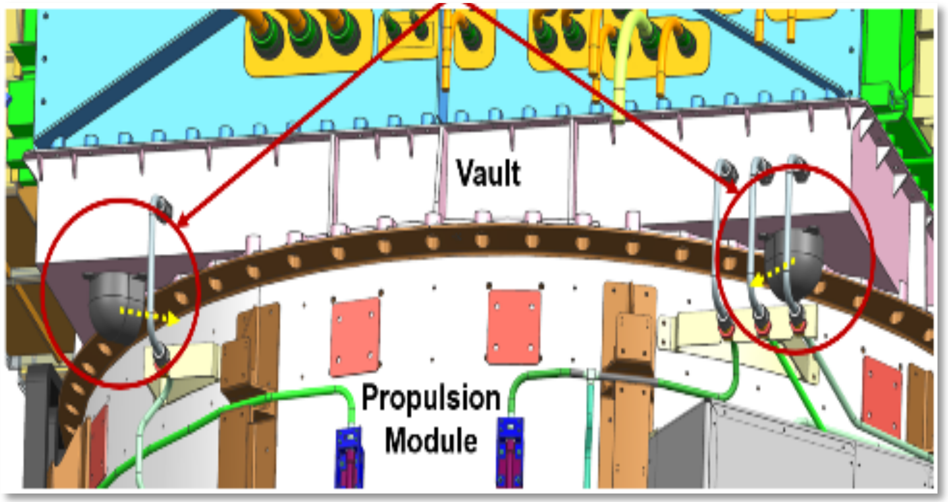
55mm diameter vent hole

A copper mesh disk inserted into the 2mm recessed 80mm dia. hole

A stainless steel cover plate (1.2mm thick) is fastened on to compress and secure the copper mesh disk

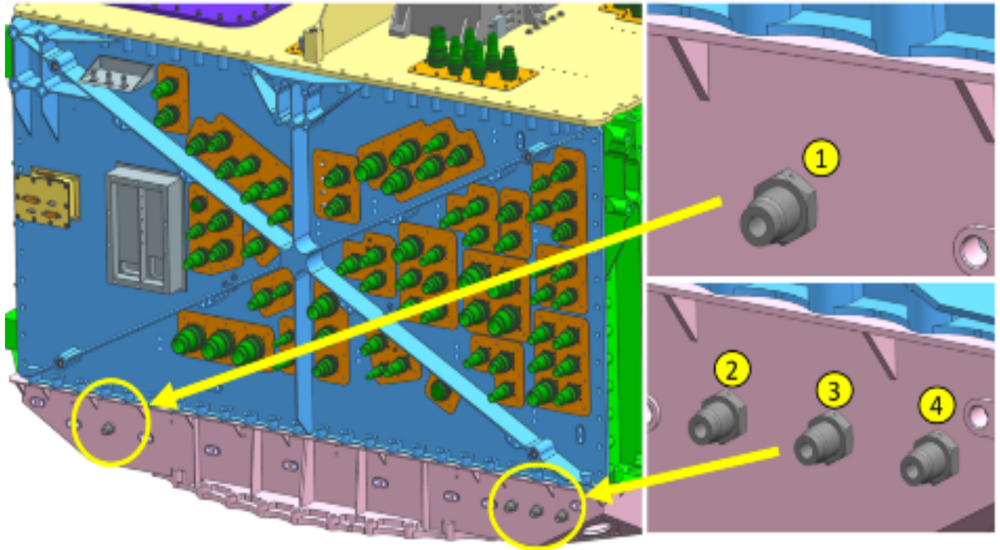
A radiation cover is placed directly over the vent hole



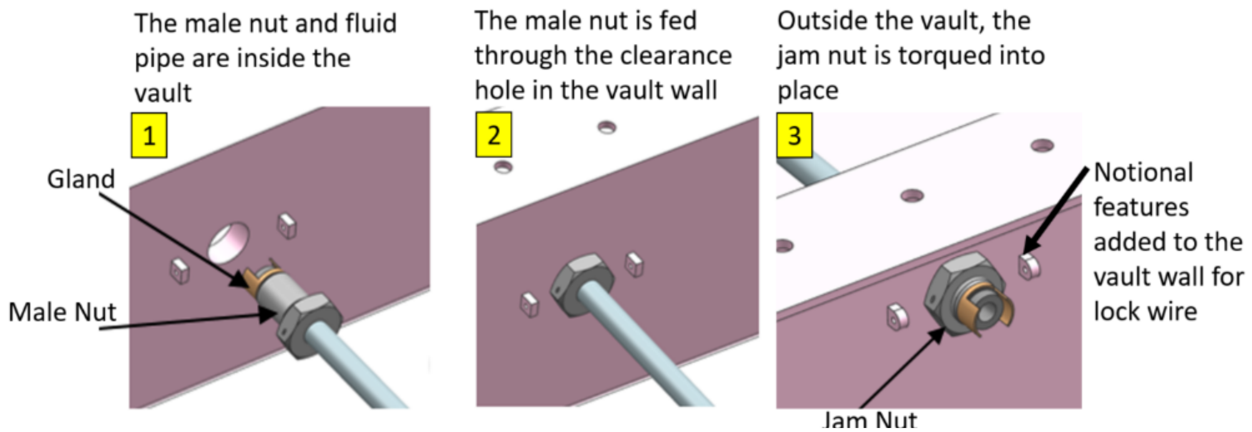



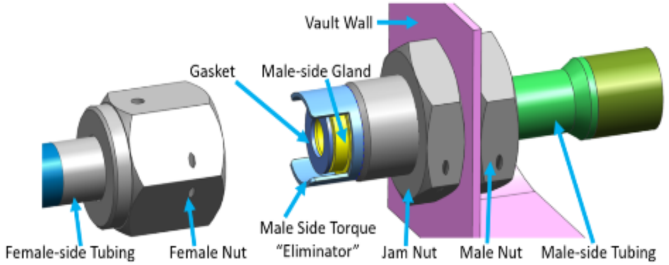
# Fluid Lines

- In total, four fluid lines penetrate the vault
- These four fluid lines are the propulsion module supply line, propulsion module return line, radiator supply line, and radiator return line.
- The fluid lines penetrate the +X side of the -Z panel wall, which is 9.2mm thick Al 7075.
- Originally, fluid lines penetrated the vault via Omnisafe quick disconnect mechanical fittings, as shown below (changes shown in back up slides)




**(1) propulsion module supply line, (2) radiator supply line, (3) radiator return line, and (4) propulsion module return line.**



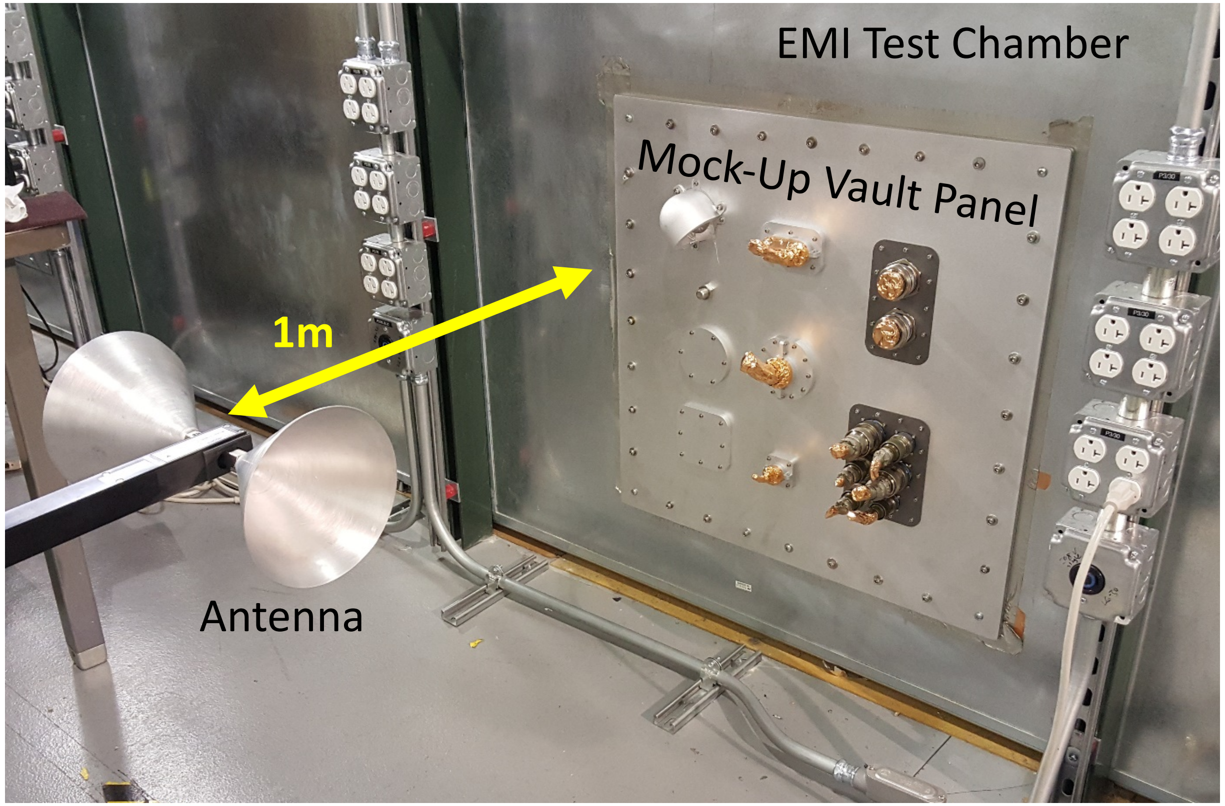



# Mock-Up Vault Panel EMI Test

# Purpose of EMI Test

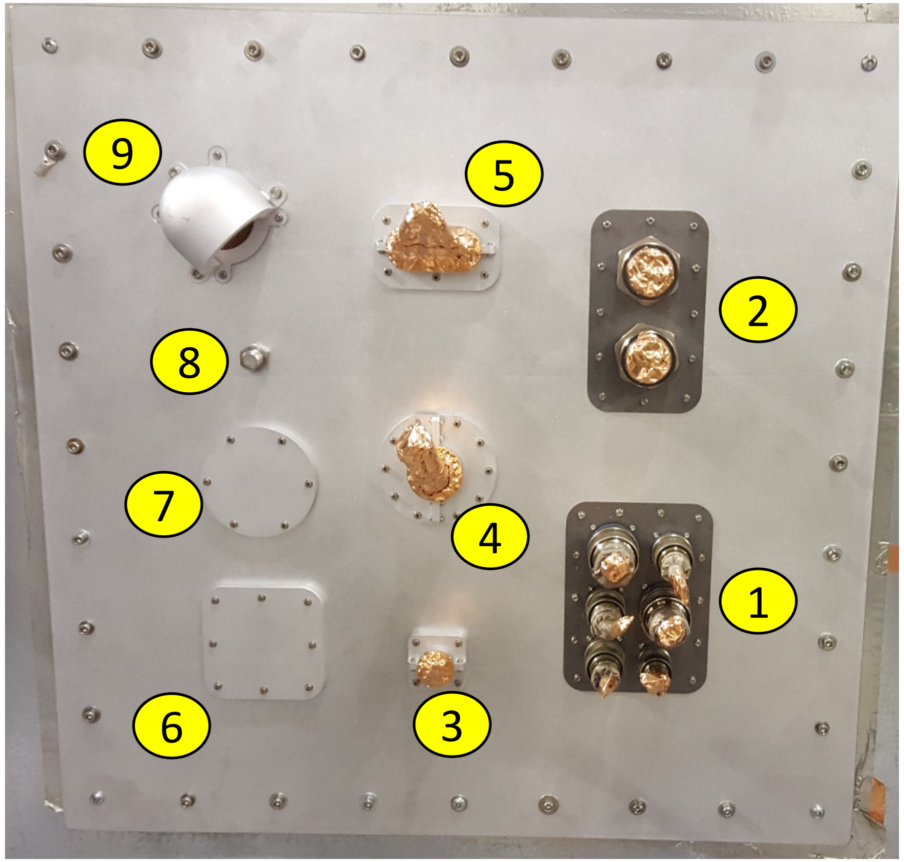
- Assess the EMI shielding effectiveness of the vault penetrations
  - Reduce risk by confirming the panel design meets shielding effectiveness requirement of at least 70 dB when measured 1m outside the vault
  - Verify shielding effectiveness of copper mesh in vent hole configuration
  - Assess shielding effectiveness of jam nut versus flanged receptacles
  - Assess EMI seal around seams of each penetrations

- Proof of concept on overall assembly and design of novel penetrations
- An EMI test was performed in the JPL EMC Lab in March 2018



# Test Article: Mock-up Vault Panel

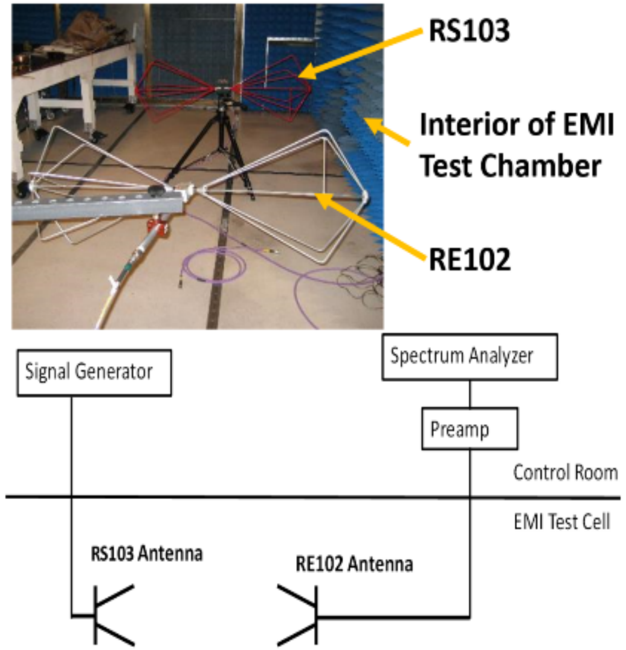
- The mock-up vault panel is a scaled down version of the vault X panels with variations of vault penetrations
- Mock-Up Vault Panel Dimensions: 28” x 28” x 0.4”




| # | Description of Penetration |
|---|---|
| 1 | A Ta10W connector adapter plate that consists of 6 circular connectors. |
| 2 | A Ta10W connector adapter plate that consists of 2 jam-nut circular connectors. |
| 3 | A clamshell for a ~10 mm diameter single cable that penetrates the vault via a circular through hole. |
| 4 | A clamshell for multiple cables bundled together through a circular through hole. |
| 5 | A clamshell for multiple cables that penetrate the vault via a slotted hole. |
| 6 | A generic cover plate that acts as an access panel on the vault. |
| 7 | A torturous labyrinth path seam interface with no EMI gasket. |
| 8 | A 3/8” size nut and bolt that represents a single fluid line mechanical fitting. |
| 9 | A vent hole with copper mesh compressed under a cover plate, and a radiation cover. |

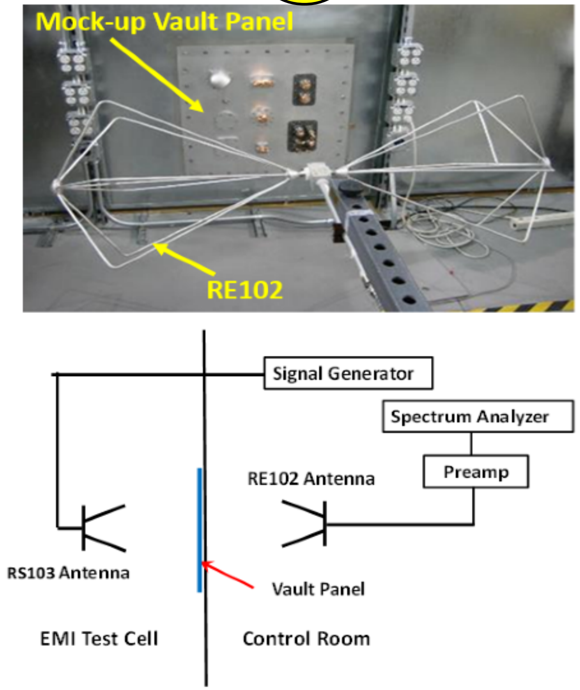
# Test Setups

1



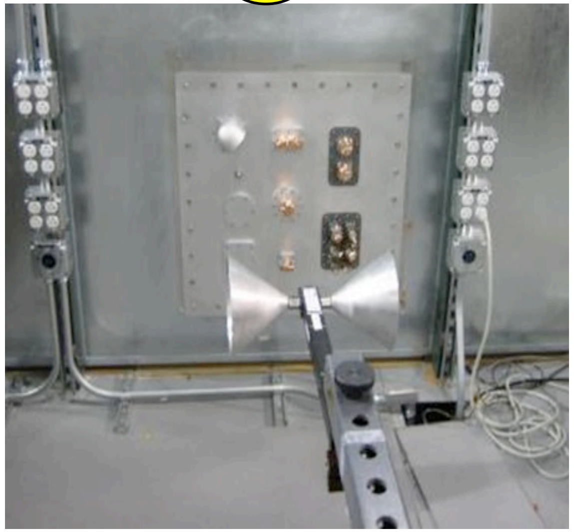

- Baseline calibration of E-field versus signal generator (SG) drive power level.
- SG at -5dBm, antennas 2m apart

2



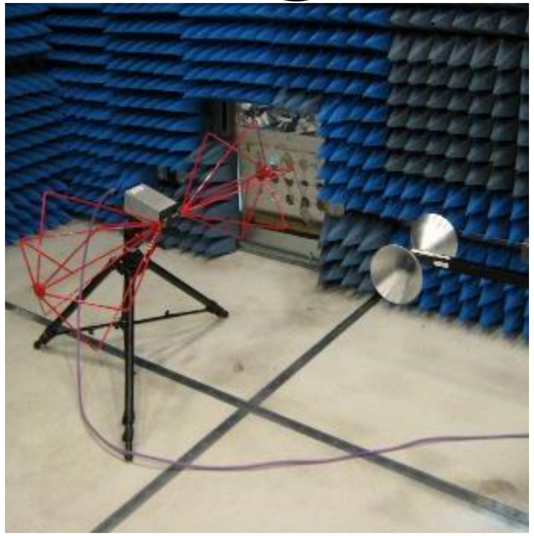

- Measure shielding response of mock-up vault panel
- SG at +10dBm, antennas 2m apart
- RE102 antenna larger than the width of the panel (could skew results)

3



- Repeated shielding response test with a mini-bicon antenna
- SG at +15dBm, antennas 2m apart

4



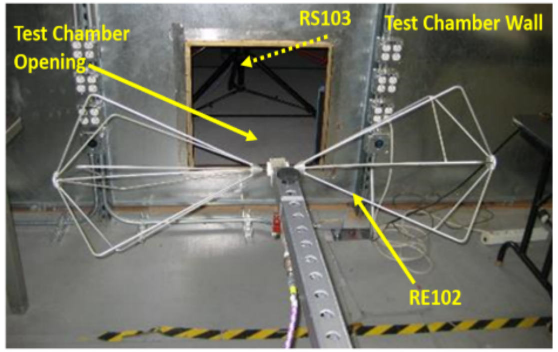
- Mini-bicon antenna moved inside the test chamber to obtain baseline reference data.
- SG at +15dBm, antennas 1m apart

# Shielding Effectiveness Test Results

1
- SG at *-5dBm*, antennas 2m apart
- E-Field (60Hz): **87.6** dBµV/m

2
- SG at *+10dBm*, antennas 2m apart
- E-Field (60Hz): **17** dBµV/m

**Shielding Effectiveness:**
**SE = 87.6 – (17 – *10* – *5*) = 85.6 dB**




***The RE102 antenna is larger than the width of the chamber opening. Therefore, this setup potentially over-states the shielding response.***

3
- SG at *+15dBm*, antennas 2m apart
- E-Field (60Hz): **10.65** dBµV/m

**Shielding Effectiveness:**
**SE = 87.6 – [10.65 + 18 – (*15* + *5*)] = 79 dB**

**Using test setup (1) as baseline calibration**

4
- SG at *+15dBm*, antennas *1m* apart
- E-Field (60Hz): **94.2** dBµV/m

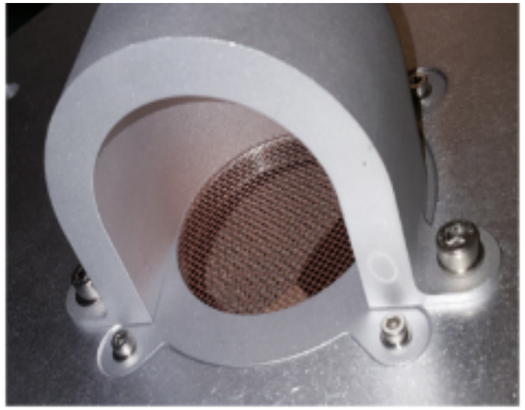
**Shielding Effectiveness:**
**SE = (94.2 + 18) – (10.65 + 18) – 6 = 77 dB**

**Using test setup (4) as baseline calibration**

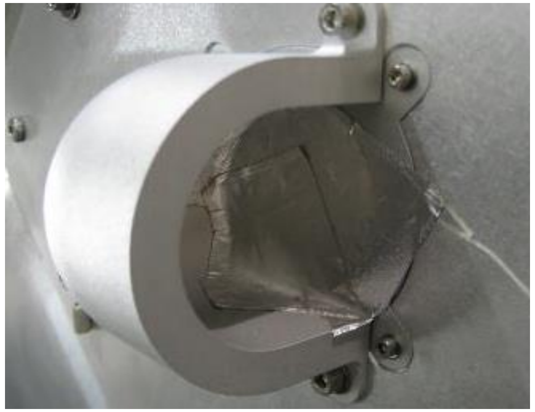
**1m to 2m Offset Correction: 6 dB/m**
**Antenna Factor Correction: 18 dB/m**

# Additional Test Results – Copper Mesh Shielding Effectiveness

- The vent hole EMI shielding copper mesh was covered with EMI tape to assess its shielding effectiveness
- Results showed a delta in the E-field of 0.7 dBμV/m between taped and non-taped copper mesh
- Copper mesh has good shielding effectiveness



Exposed Copper Mesh



Copper Mesh covered with EMI Tape

# Additional Test Results – Jam Nut vs Flanged Receptacle Connectors

- Hypothesis was that jam-nut connectors provide better EMI SE compared to the flanged receptacle connectors
- All penetrations on the mock-up vault panel were shielded with aluminum foil except the connector of interest
- Results showed that the E-field was measured to be 11.68 dBµV/m for exposed jam nut connectors, and 11.72 dBµV/m for exposed flanged receptacle connectors.
- The results were essentially the same, indicating no discernable difference in shielding effectiveness between jam nut and flanged receptacles.

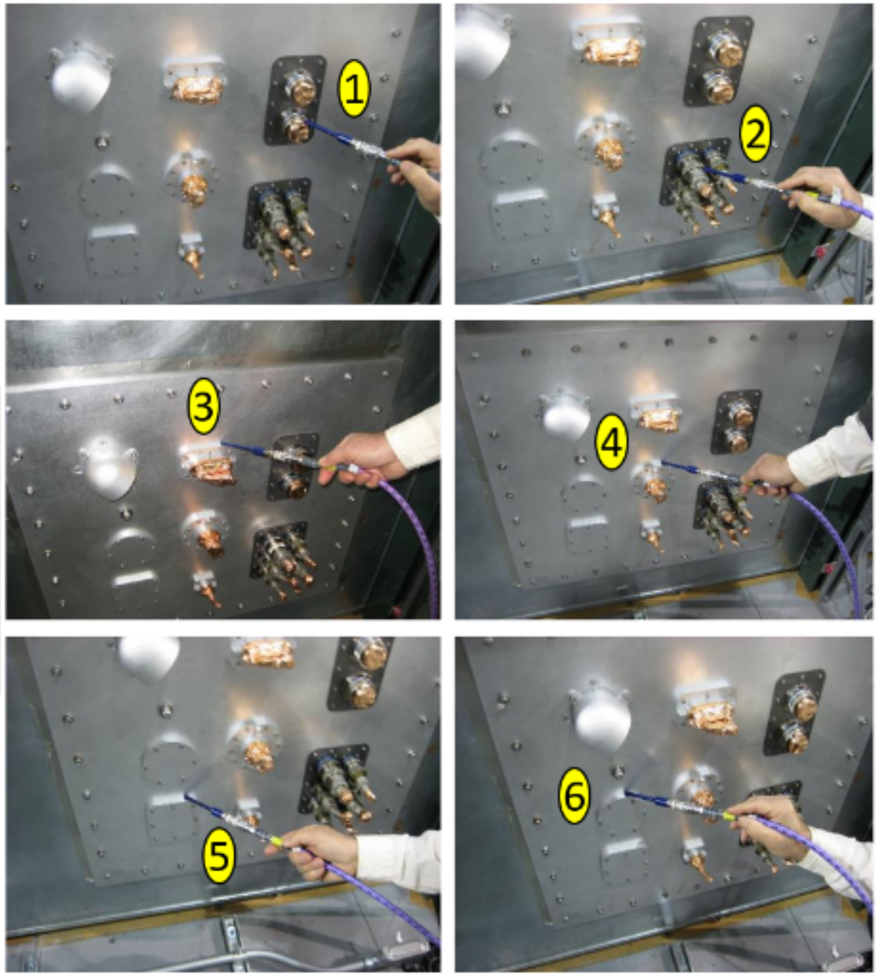
Jam Nut connectors exposed

Flange Receptacle connectors exposed

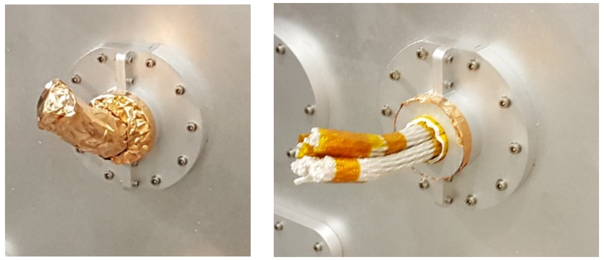
# Additional Test Results – Shielding Effectiveness of Seams

- A near field probe was used to probe the seams of the penetrations on the mock-up vault panel to assess EMI leakage
- The RS103 antenna was driven inside the test chamber and the probe was used at a selected seam to measure leakage.
- The signal generator power was increased to 20 dBm to provide more signal, and the probe output was connected to the Sonoma preamp, with its output routed to the spectrum analyzer. This configuration enabled measurement of very low signal levels.
- Results showed very low leakage levels →

| # | Signal (dBµV) |
|---|---|
| 1 | 5.6 |
| 2 | 7.8 |
| 3 | 8 |
| 4 | 8.1 |
| 5 | 8.1 |
| 6 | 7.5 |




- The EMI leakage around the clamshell seam increased from 8.1 dBµV to 39.8 dBµV when the copper tape was removed



Removed copper tape

**Copper tape is necessary to seal the clamshells for EMI signals!**

# Summary

# Summary

- The Avionics Vault is a multifunctional box structure that houses radiation sensitive electronics for Europa Clipper
- All seams and additional materials used to close the vault for radiation need to provide a shielding effectiveness equivalent to 9.2 mm thick Al 7075.
- The vault is also required to achieve an EMI SE of at least 70 dB at the REASON radar frequencies of 9 MHz and 60 MHz when measured at 1m from the vault panel.
  - *This is achieved using Spira-Shield EMI gaskets, Labyrinth L-configuration seams, and less than 2 inch fastener spacing.*
- In total, there are four main types of penetrations on the vault:
  - *Receptacle connectors, pass-through cables, fluid lines, and vent holes.*
- To confirm that these novel penetrations provided adequate EMI shielding, an EMI test was performed at JPL on a mock-up vault panel.
- The results showed a shielding effectiveness of at least 77 dB for the mock-up vault panel
- In addition, the flange mounted connectors and jam nut connectors exhibited similar EMI SE results.
- The EMI test verified the shielding effectiveness of the copper mesh and copper tape for vent holes and clamshells
- Since the flight panels will be much larger and include many more penetrations, there will be testing of a flight-like vault to confirm its EMI SE is compliant with requirements

# Acknowledgements

Authors

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- William A. Hatch
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- Jim Baughman

Questions?

# Back Up Slides

# Europa Clipper Instruments

| # | Instrument Title | Acronym |
|---|---|---|
| 1 | Europa Thermal Emission Imaging System | E-THEMIS |
| 2 | Mapping Imaging Spectrometer for Europa | MISE |
| 3 | Europa Ultraviolet Spectrograph | UVS |
| 4 | Europa Imaging System | EIS |
| 5 | Radar for Europa Assessment and Sounding: Ocean to Near-surface | REASON |
| 6 | Interior Characterization of Europa using Magnetometery | ICEMAG |
| 7 | Plasma Instrument for Magnetic Sounding | PIMS |
| 8 | Mass Spectrometer for Planetary Exploration | MASPEX |
| 9 | Surface Dust Mass Analyzer | SUDA |

# Comparison of Material Properties

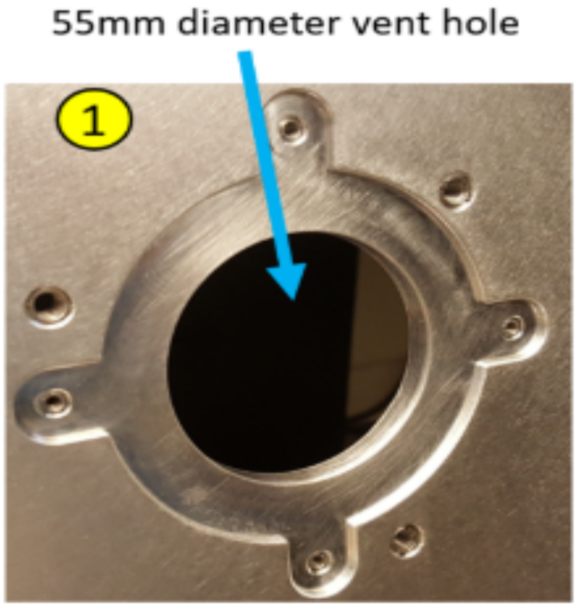
| Metal | Radaition Shield Thickness (mm) | Density (g/cm^3) | Electrical Resistivity (Ω*cm) | Elastic Modulus (GPa) | Ultimate Tensile Strength (MPa) | Yield Strength (MPa) | Thermal Conductivity (W/m-K) |
|---|---|---|---|---|---|---|---|
| Al 6061-T6 | 9.6 | 2.7 | 4.00E-06 | 68.9 | 310 | 276 | 167 |
| Al 7075-T73 | 9.2* | 2.81 | 4.30E-06 | 72 | 505 | 435 | 155 |
| Ta10W | 1.3* | 16.9 | 1.80E-05 | 205 | 550 - 620 | 482 | 54 |
| 316 SS | 3.2 | 8 | 7.40E-05 | 193 | 579 | 290 | 16.2 |
| Tungsten | 1.3 | 19.3 | 5.50E-06 | 400 | 980 | 750 | 163 |

Note that the radiation shield thickness of Al 7075 and Ta10W were determined from a spherical shell dose-depth curve. All other thicknesses were estimated using equation below. All materials properties were found from Metal Suppliers Online[2].

$$t_{new} = 9.2\left(\frac{\rho_{Al\ 7075}}{\rho_{new}}\right)$$

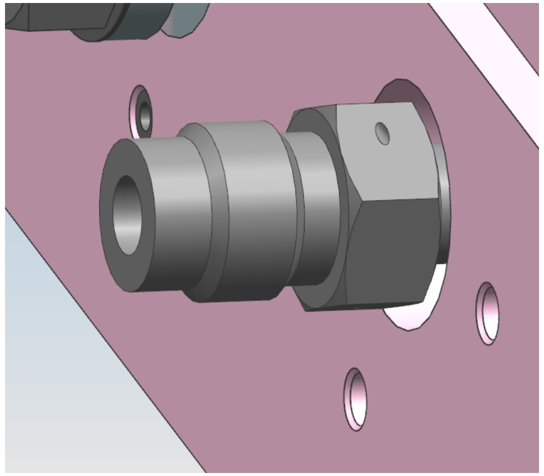
# Sizing Vent Holes

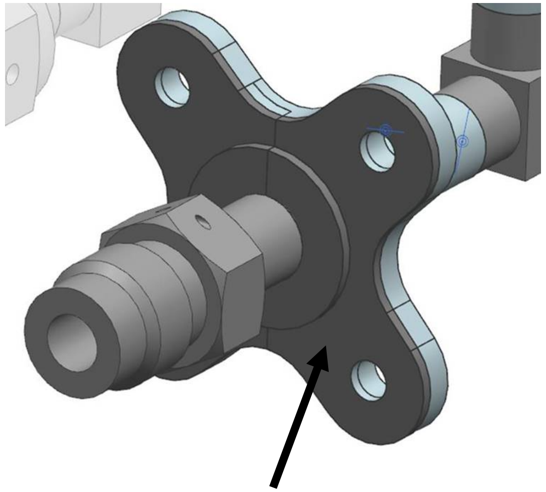
- A good rule of thumb for venting is to have the void volume of the assembly divided by the total area of the vent hole to be less than 50,800 mm.
- Assuming the vault is completely empty, the void volume of the vault is approximately 1.12 $m^3$.
- Assuming that there are four vent holes, the diameter of each vent hole would need to be about 84 mm to satisfy the rule of thumb for venting.
- A significant amount of electronic boxes, support brackets, connectors, and cables reside inside the vault.
- This will drive the void volume down, and thus the required vent hole area down.
- In addition, the vault can probably handle higher levels of pressure during launch since the vault panels are significantly thicker and stronger than typical spacecraft chassis.
- With these factors in mind, the diameter of the four vent holes were set to 55 mm based on the space available at each of the four corners of the vault.
- Analysis will be done to verify that these reduced size vent holes are adequate for venting the air inside the vault.



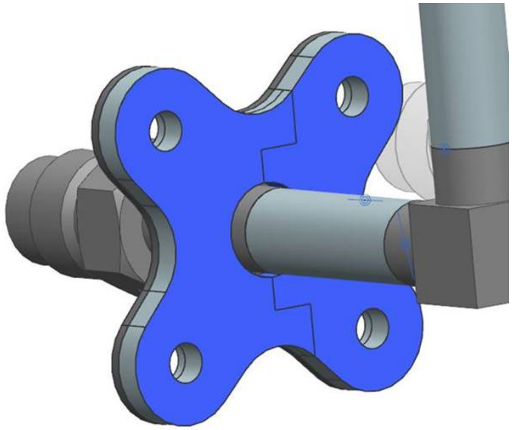
# Changes in Fluid Line Penetrations

- Recently found out that two of the fluid line penetrations need to be thermally isolated from the vault wall
- A concept of these penetration looks like the following:





Thermal isolation interface



- Utilizes a Labyrinth L-configuration seam to close for EMI signals